



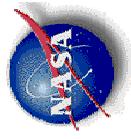
Wire Integrity Research (*WIRe*)

Jim Cockrell

WIRe Project Manager

April 03





Wire Integrity Research (WIRe) Presentation Outline

- NRC Question
- Why WIRe? - Purpose and Background
- Research Objectives
- Approach
- Status
- Backup slides/Details





NRC Question -

- "WIRe: update on project needed, particularly on how plans have been adjusted to target general techniques for multiple systems as well as what steps have been taken to take on a leadership role in this area."





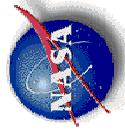
Answer -

- "WIRE: update on project needed, particularly on how plans have been adjusted to target general techniques for multiple systems as well as what steps have been taken to take on a leadership role in this area."

Wire Integrity Research (WIRE)

Why WIRE? - Purpose and Background





WiRe Purpose

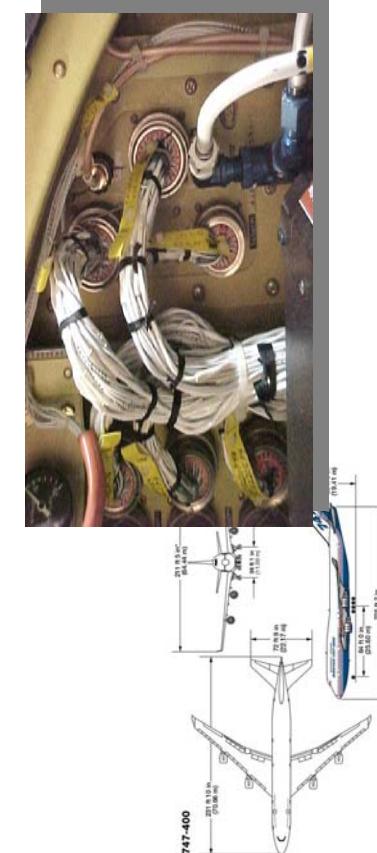


Goal:

- Provide tools and methodologies to the aerospace community that increase safety while reducing operating costs of aerospace vehicle wiring systems.

Definition:

- “A wiring interconnection system includes insulated electrical conductors, connectors, relays, circuit breakers, and power distribution panels.” - JCIAA
Wiring S&T Steering Group





WiRe Purpose



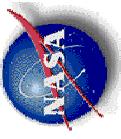
Objectives:

- ▶ Create new methods to model and assess risks associated with wiring systems
- ▶ Advance wire integrity prognostic tests based on physics models
- ▶ Optimize assessment/data acquisition/repair disposition schedules with database integration
- ▶ Enable risk-based wiring maintenance

Target application:

- ▶ Space Shuttle Orbiter wiring systems; with general applicability to NASA, DOD, and Civil aerospace vehicles - legacy and next-generation





WiRe Background



- Recent issues heightened concerns about aging wiring systems within NASA, military and civilian aerospace
 - STS 93, STS-97, STS-112;
 - TWA 800, Swiss Air 111;
 - NSTC IWG Review of Federal Programs for Wire System Safety
 - aging Naval Aviation, Air Force fleets
- General Questions:
 - Can risk of aerospace vehicle wiring systems, including human factor contributions, be quantitatively modeled with useful results for decision-makers?
 - Can life-cycle costs be reduced, while reducing risk?
 - Can a wiring system be managed pro-actively instead of reactively?





Answer -

- "WIRE: update on project needed, particularly on how plans have been adjusted to target general techniques for multiple systems as well as what steps have been taken to take on a leadership role in this area."

Research Goals

Wire Integrity Research (WIRE)





WiRe Pilot Study



- Aug 2000, WiRe Pilot Study evaluated 25 integrity test equipment and 3 Test Management Software tools

- *It was the first comparison study of wire integrity testers*

WiRe Pilot Study Conclusions

- Reflectometry locates hidden faults; can detect “subtle” defects
- But - COTS reflectometry testers aren’t ready for deployment
 - Bulky; require expert interpretation; need greater sensitivity; are invasive
- COTS Test Management SW packages could minimize invasiveness; auto-generate wire fault trees; facility repair disposition and trend analysis



Oral presentation
Photo credit: NASA



WIRe Pilot Study Recommendations

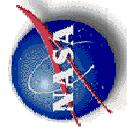


WIRe Pilot Study Recommendations

- Develop automated integrity test equipment based on reflectometry
 - Develop Wire Risk Assessment Tool
 - Evaluate cost/risk business cases with wiring risk models
 - Use Test Management Software Tools to expedite inspections/tests
 - Integrate COTS TM SW package with KSC wire, PR databases
 - Prioritize inspection, tests based on risk and schedule
 - Create 3-D CAD wire harness; improve PR resolution and facilitate upgrades
 - WIRe Pilot Study Final Report posted on www.wire.nasa.gov
- *Unique Approach: proactive, risk-informed wire system management*
- ⇒ ECS sponsors 5-year WIRe project



WiRe Three Research Thrusts

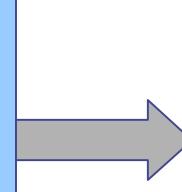


Hybrid Reflectometer

- Diagnostics
- Prognostics

WiRe Risk Assessment

- Risk Models
- Human Factors



Test Management Software

- Risk-informed Maintenance, Disposition
- Prognostic Application, Risk Mitigation



Technology Transfer

- Publication
- Inter-agency Coordination



Research Questions



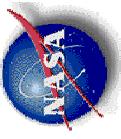
► Hybrid Reflectometer

- Is there information in characteristic impedance of wire dielectric (polyimide insulation) to distinguish damage from connectors, splices, noise?
- Can algorithms be developed to automate this in instrumentation?
- Can reflectometry stimuli be “tuned” to illuminate defects, hidden behind ordinary impedance discontinuities (connectors, etc) while attenuated by long cable runs?

► Wire Risk Assessment

- Can risk models of wiring systems, and the human processes that impact them, be useful predictive tool?
- Can risk inform decisions such as
 - ◆ Improved maintenance procedures? scheduling decisions?
 - ◆ Choices about protective devices? Other mitigation?
 - ◆ Design trades?
 - ◆ Introduction of new test methods/technologies/tools?
- Best approaches for future data collection?
- Where to look for trends?





Research Questions



► Test Management Software

- Can wiring/schedule/labor database integration and automation streamline wire integrity assessment, management, diagnostics, and problem disposition - lowering wiring system life-cycle costs without incurring additional risk?
- Can risk-informed maintenance be applied to aerospace vehicle wiring systems?
- Can 3-D visualization of wire harnesses aid trend analysis and risk mitigation effectively in legacy vehicles?



WIRe Leadership



- ▶ Hybrid Reflectometer
 - First study of response of wiring to test stimuli based on 3-D computer models of EM properties
 - First study of fundamental capabilities/limitations of reflectometry
 - ◆ (Others are making incremental improvements to reflectometry tester hardware)
 - U of Utah, Dynacs (KSC), Goodrich, others are collaborating with WIRe in exchange for use of WIRE models
- ▶ Wire Risk Assessment
 - First risk assessment of aerospace vehicle wiring
 - New modeling methodologies for wire operations may result
 - ◆ NRC has studied wire aging mechanisms, but not risk
 - ◆ FAA has recently launched a feasibility study
 - ◆ No Shuttle FMEA/CIL of wiring exists





WiRe Leadership

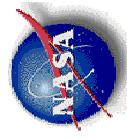


► Test Management Software

- First effort at risk-informed maintenance for vehicle wiring
- Integration of Shuttle wire problem reporting/corrective action (PRACA), standard operating procedure paperwork (TPS), and technical personnel (PeopleSoft) databases will roll into Digital Shuttle taxonomy research
- First use of 3-D visualization tools for operations, risk modeling, trend analysis



WiRe Research Collaborators



<u>POC</u>	<u>Org</u>	<u>Role</u>
Jim Cockrell	ARC	Project Manager
Paul Keller	ECS Digital Shuttle	Investigator, 3-D Wire (TMSW)
Dana Lynch	ARC	Hybrid Reflectometer PI
Dr. Pedro Medelius	Dynacs, KSC	Hybrid Reflectometer collaborator
Dr. Cynthia Furse	Univ. of Utah	Hybrid Reflectometer collaborator
Dr. Michael Frank	Safety Factors Assoc	Wire Risk PI
Dr. Robert Mulvihill	Hernandez Eng'g Inc	Wire Human Factors



Coordination with Interagency and Private efforts



Sponsoring Agency	Organization
Navy Navair Pall Armason (and others)	NAVVAG, CHROME, CM Technology ECAD, Eclypse SWR
Air Force Research Lab George Slenski	Aging Aircraft Wiring Working Group; Wire Integrity Tester Evaluation Program
FAA Hughes Technical Center Rob Pappas	Aircraft Wire Risk Assessment, CM Technology Excited Dielectric
Joint Aeronautical Commanders Group	Joint Council on Aging Aircraft Wiring Science and Technology
Office of Science and Technology Policy Charlie Huettner, Bill Harris (JSC)	Wiring System Safety Interagency Working Group

ECS WIRE participates in TIMS with each Agency

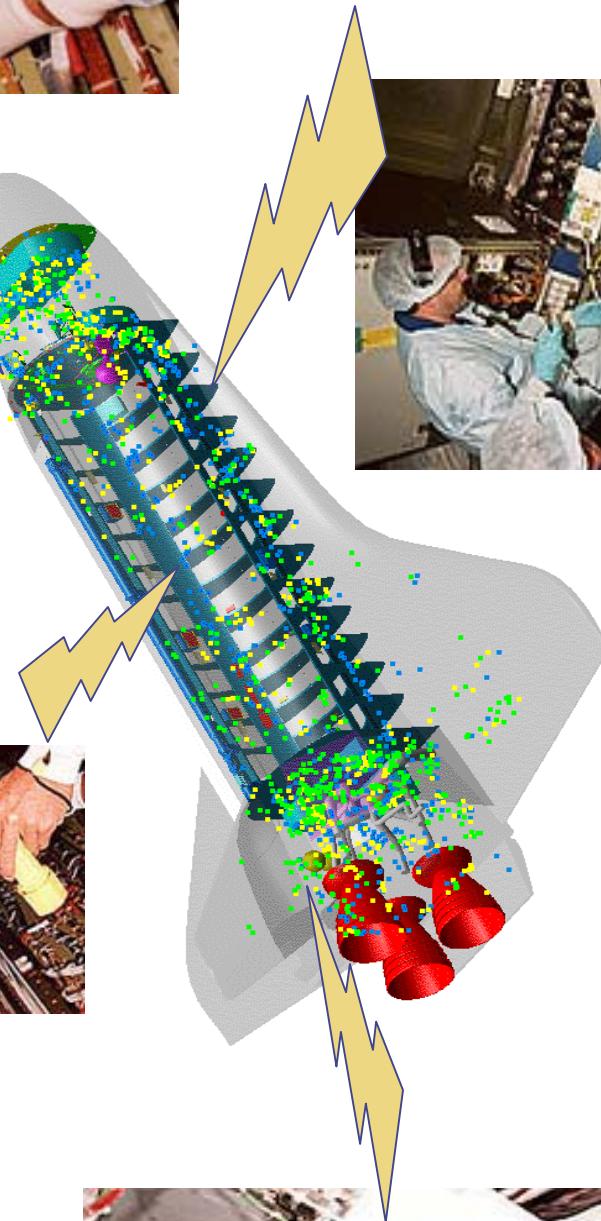
ECS WIRE is a member of JCAA Wiring S&T and WSSIWG

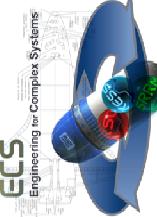
WIRE hosts www.wire.nasa.gov as forum for Inter-Agency Aging Wiring Community



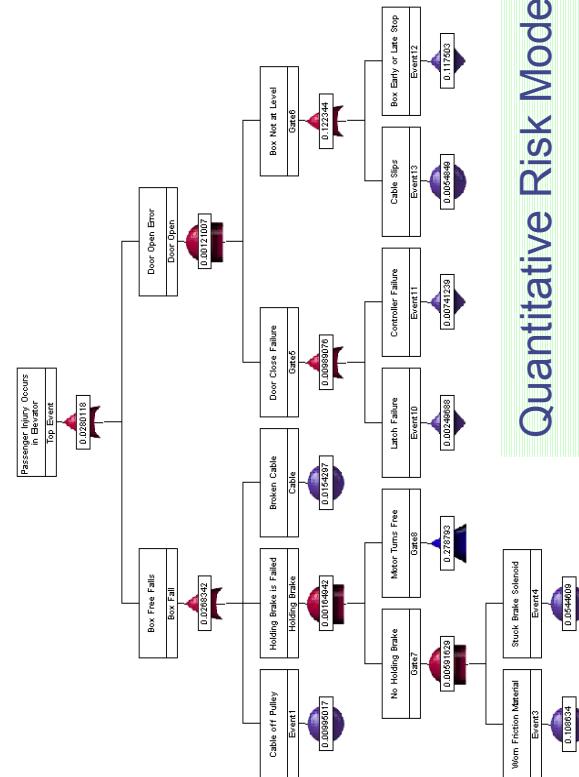
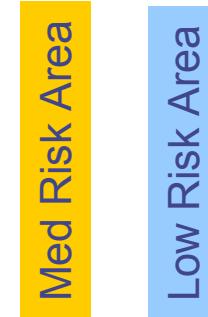
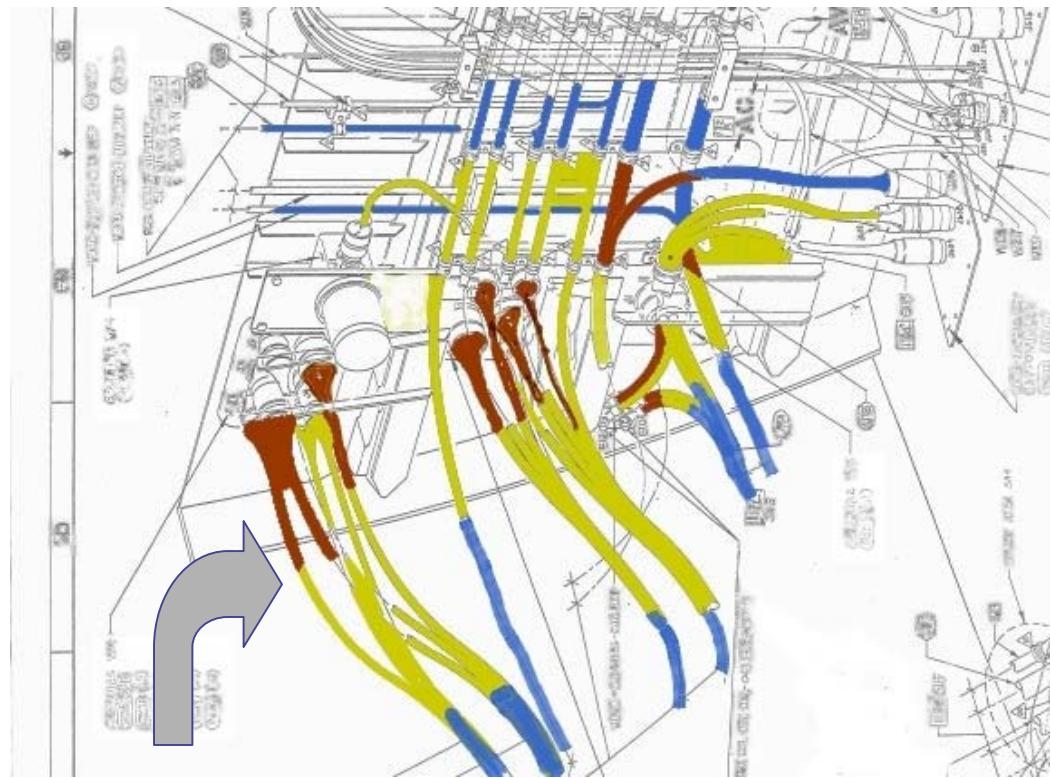


Can we go from labor-intensive inspections...

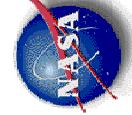




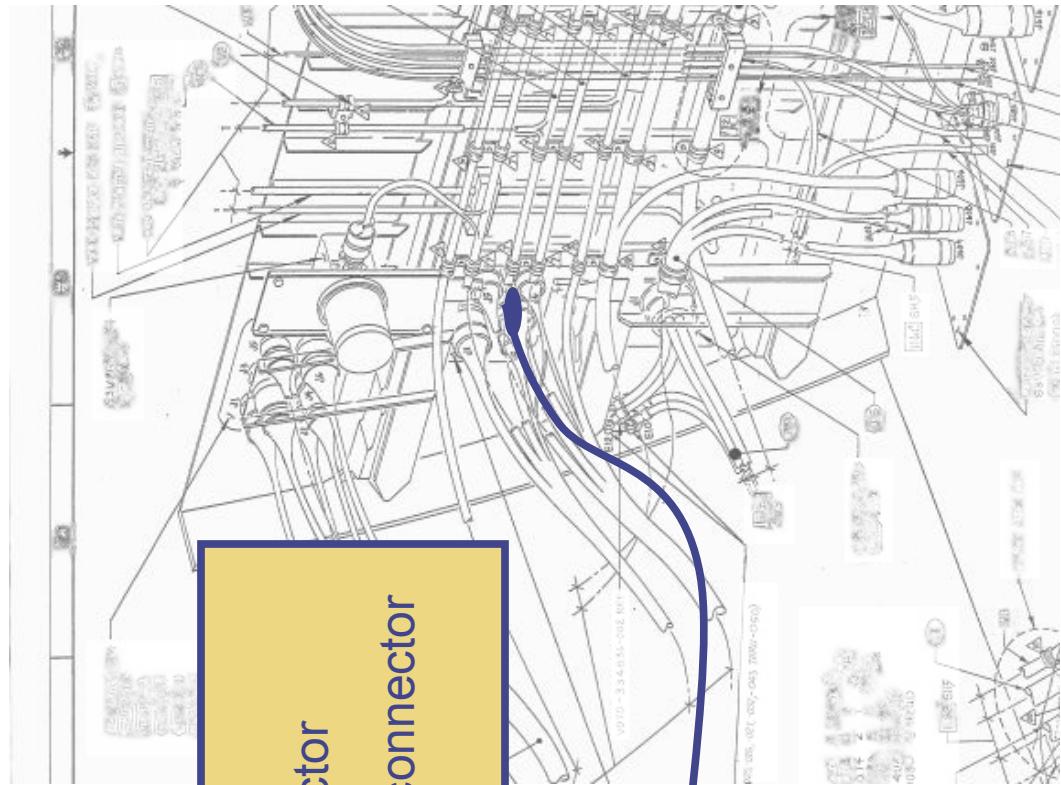
...to risk-advised maintenance...



Quantitative Risk Model
(including Human Factors)



...with automated wire integrity assessment?



Open Circuit - 4.35m from connector
Insulation damage - 2.75m from connector

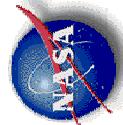
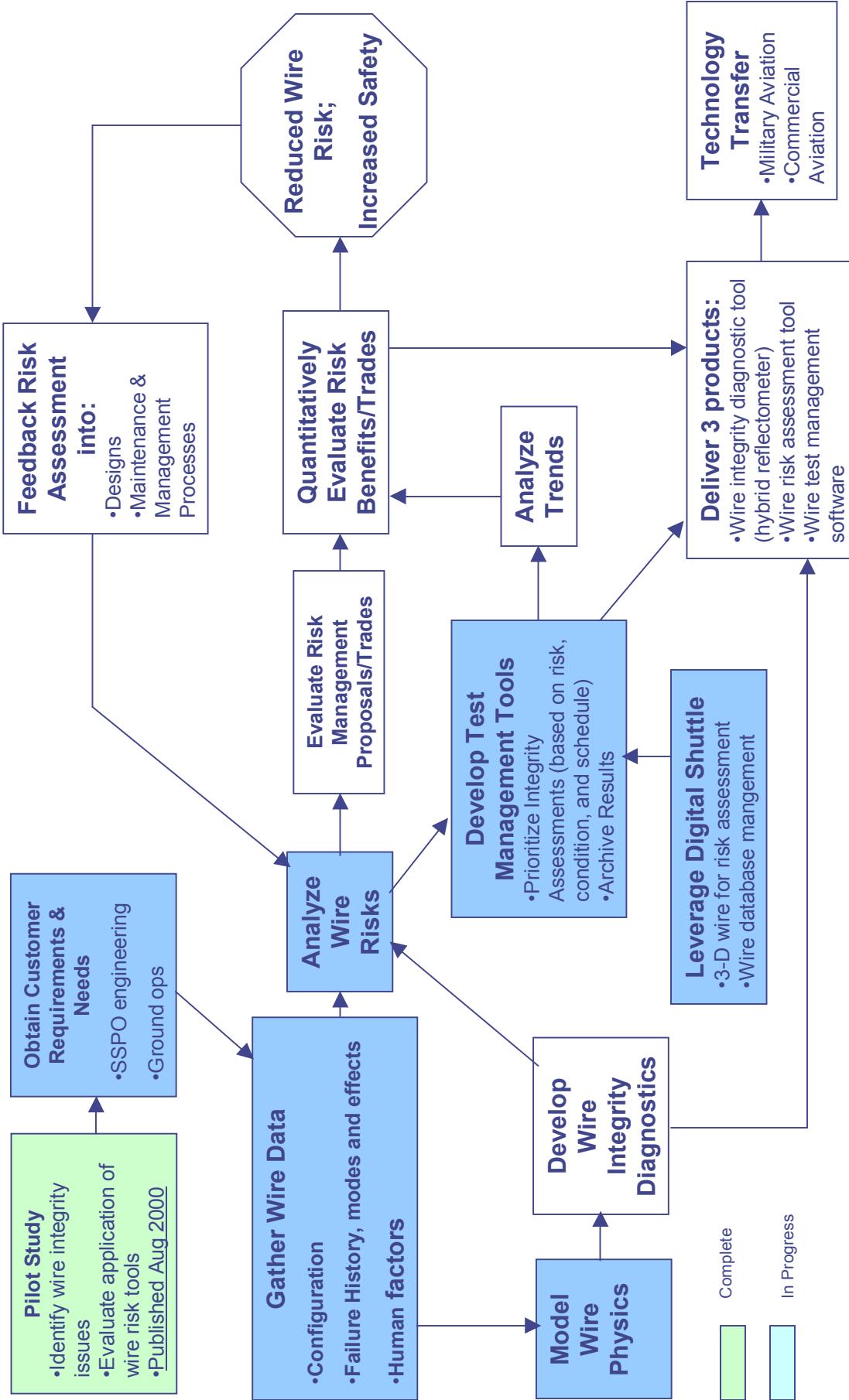


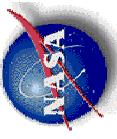
Approach

Wire Integrity Research (WIRE)



WiRe Development Approach





Four WIRe Tasks



Hybrid Reflectometer (FY02 - FY05)

- Build computational models of wire, defects responses to TDR, FDR, SWR
- “Tune” stimuli to distinguish defects from wire features; automate analysis
- Produce wire defect diagnostic testers with industry partner

Wire Risk Assessment (FY02 - mid-FY04)

- Investigate use of quantitative risk assessment techniques for optimizing Orbiter wire maintenance procedures

FY04-FY06 Build Wire Risk Assessment Tool

Wire Test Management Software - (FY03 - FY06)

- Wire design, problem reporting, rework/retest, work authorization database integration facilitates maintenance/management - leverage Digital Shuttle
- Digital Shuttle 3-D visualization aids trend analysis, risk mitigation
- Goal: Risk-Informed Maintenance

Technology Transfer (FY02-FY06)

- Coordinate with Interagency Wire S&T efforts
- Publish results; host www.wire.nasa.gov, technical memoranda, conference papers



WIRe Technology Road Map



Activities

Hybrid Reflectometer

Model Wire Physics

“Tune” test stimuli

Automate Test Instruments

Wire Risk Assessment

Test Management SW Tools

Leverage Digital Shuttle technology

Validation/ Technology Transfer

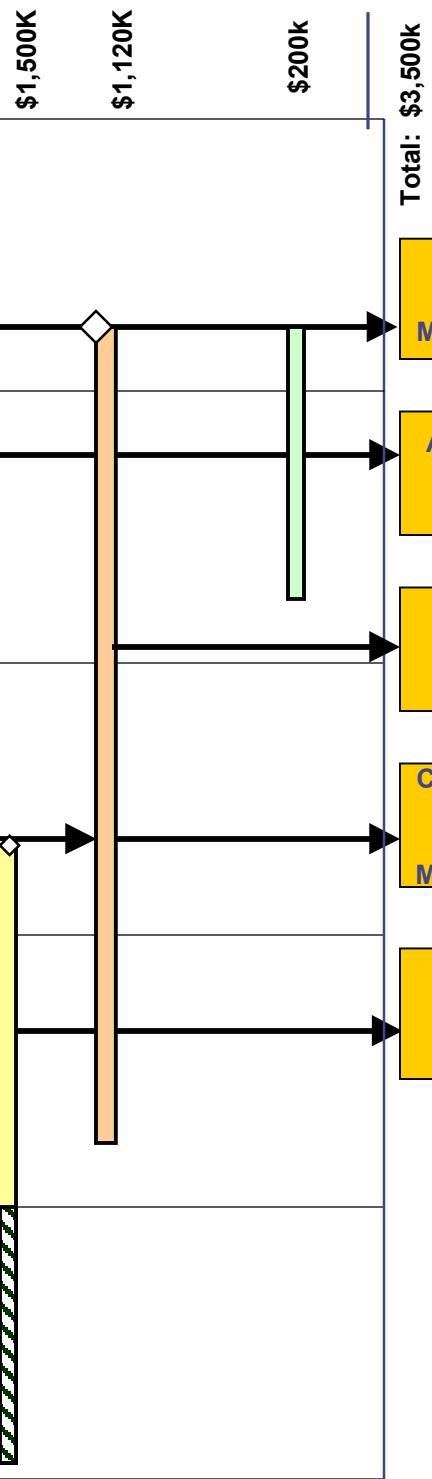
FY06

FY05

FY04

FY03

FY02

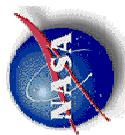


Deliverables

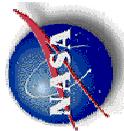
WiRe Deliverables



- ▶ Publications to date:
 - *Wire Integrity Research Pilot Study*, Aug 2000
 - *NASA Hybrid Reflectometer Project*, Aging Aircraft Conference, Sept 2002
 - *A Comprehensive Toolset for Model-Based Health Monitoring and Diagnostics*, Awarded Ames Commercial Technology Office Space Act Award, 2002
- ▶ Future Deliverables:
 - **Hybrid Reflectometer**
 - ◆ Library of wiring component and defect EM physics models
 - ◆ Algorithms for automatic wire defect detection
 - ◆ Prototype “Hybrid Reflectometer”
 - ◆ Coordinate with DOD, FAA, private wire advancements
 - **Wire Risk Assessment**
 - ◆ Report: Wire Risk Assessment Cost-Benefit Analysis
 - ◆ Continuously Updated Wire Risk Model
 - **Test Management Software**
 - ◆ Report: Evaluation of laser scanning for 3-D wire harnesses
 - ◆ Prototype 3-D wire “point of interest” locator system
 - ◆ Report: Using COTS TM SW for PR, disposition automation



WiRe Customers and Benefits



► NASA Customers:

POC

<u>POC</u>	<u>Org</u>
Engineering for Complex Systems	HQ, Sponsor
Ralph Roe, Rusty Yates	JSC SSVEO Manager
Steven Sullivan	KSC Shuttle Electrical Division Chief
Ron Galvez, Lanny Plaisance	JSC SSVEO Electrical Engineering

► NASA Coordination

- KSC Ground Ops and JSC SSVEO involved in ConOps, Reqt's Analysis, and periodic reviews

► Shuttle Program Benefits

- Objective integrity testers locate “soft faults” in hidden areas
- Reduced invasiveness, labor of inspection/testing
- Improved efficiency of PR disposition - saving engineers time
- Risk-informed wiring design and maintenance saves time and labor
- Interagency developments on aging wiring leveraged for Orbiter

Status

Wire Integrity Research (WIRE)





WIRe Present Status

Finalizing MOU with SSPO, KSC Ground Ops customers Hybrid Reflectometer

- Modeled properties of coax with defects; Simulated TDR response
- Validated computer models with TDR on bench
- Delivered research paper at Aging Aircraft Conference
- Expanding wire and defects physics models library
- Partnerships with industry and academia in progress

Wire Risk Assessment

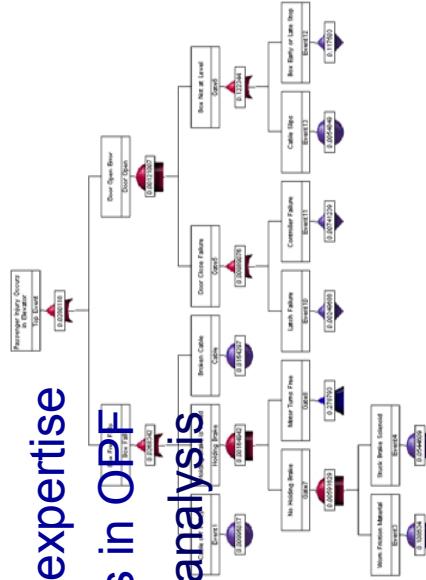
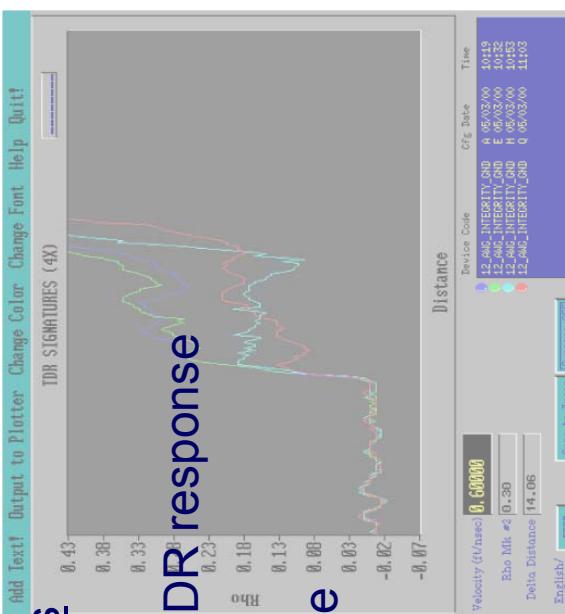
- Risk model requirements, WBS, and ConOps finalized
- Work agreement with USA and Boeing SFOC:

- Obtained “Wire Data” - PRACA, O&M, SCAN, and expertise
- Began human reliability analysis for wire processes in OPF

Created wire database from SCAN for future fault tree analysis

Wire Test Management Software

- Market survey for 3-D pointing device
- Case study laser scan for 3-D wire harnesses
- Joint task with Digital Shuttle





Wire Integrity Research (WIRe)

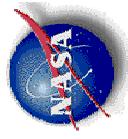
Backup Slides

- WIRe Background, Motivation
- Details:
 - Wire Risk Assessment
 - Hybrid Reflectorometer
 - Test Management Software
- ECS Org Chart
- Budget

Background

Wire Integrity Research (WiRE)



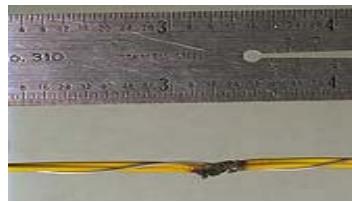


WiRe Background



Increased concern about Orbiter aging wiring systems

- Short circuit during STS-93 liftoff
- STS-97 SRB separation pyro; redundant wiring open circuits
- STS-112 hold down post pyro; likely TO connector intermittent



Subsequent investigation revealed many latent wire problems

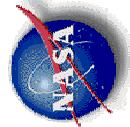
- Increased requirements for visual inspection during OMDP

Shuttle Independent Assessment Team chartered after STS-93

- Recommended several wire-related risk management actions



⇒ In response, DfS (now ECS) and SSPO initiated Wire Integrity Research (WiRe) Pilot Study -



Other Aerospace Vehicle wiring concerns



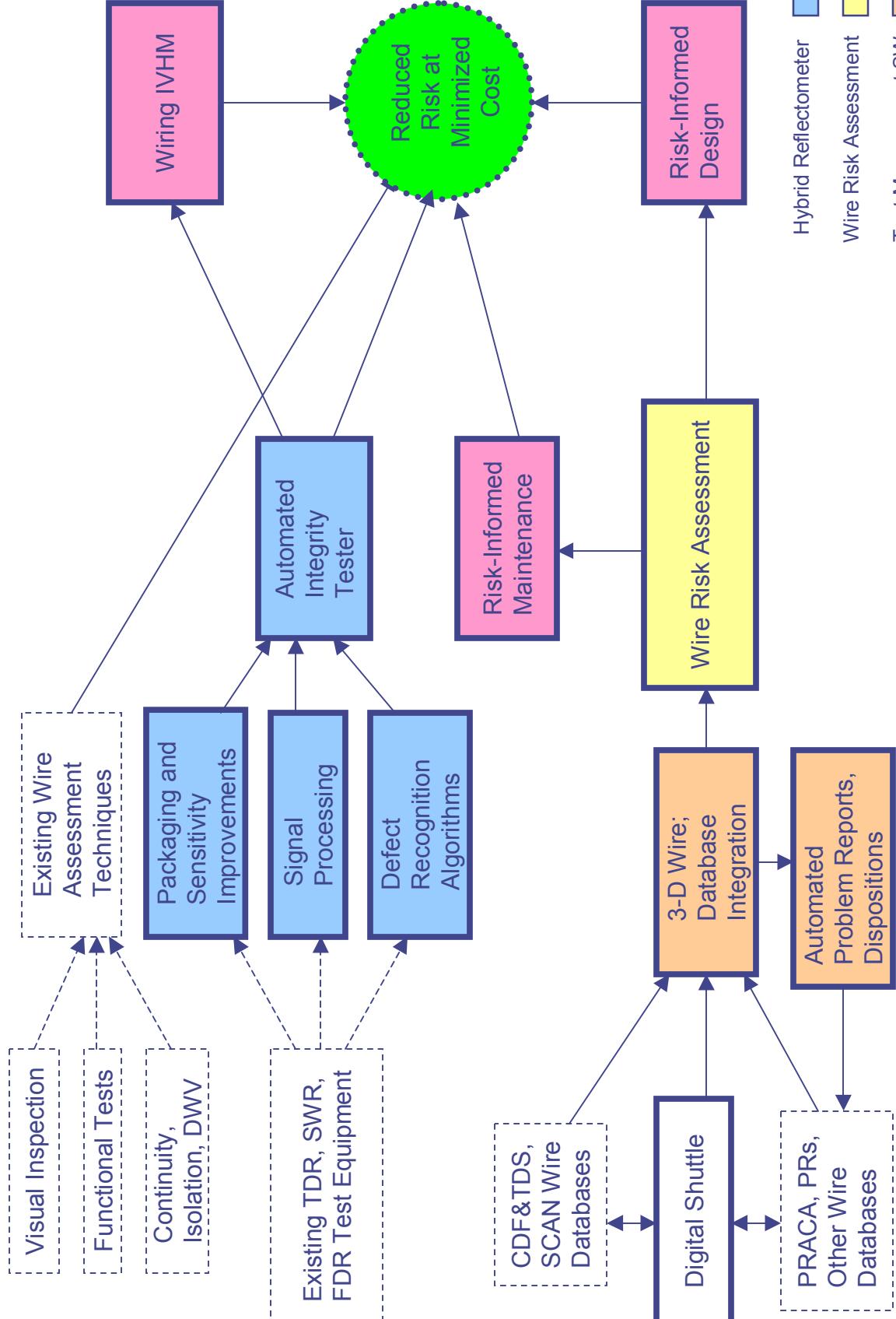
NASA is not alone in concerns regarding aging aerospace wiring:

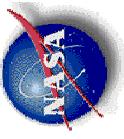
- ▶ FAA
 - TWA flight 800 - short in fuel tank, 1996
 - SwissAir flight 111 - cockpit electrical fire, 1998
- ▶ DOD
 - USAF - 140 wiring failures causing mission aborts (and rising), 2000
 - Navy - aging wiring in Naval Aviation increasing concern
 - Joint Aeronautical Commanders Group forms Joint Council on Aging Aircraft Wiring S&T steering group, 2001 - WIRE is participant
- ▶ National Infrastructure
 - White House NSTC Interagency Work Group, Review of Federal Programs for Wiring System Safety, 2000 - WIRE is participant
- ▶ WIRE delivered wiring prognostics paper, 2002 Aging Aircraft Conf.
- ▶ WIRE hosts www.wire.nasa.gov for aerospace wiring community





WIRE Technical Approach





Hybrid Reflectometer



► Hybrid Reflectometer





Hybrid Reflectometer



► Deliverables

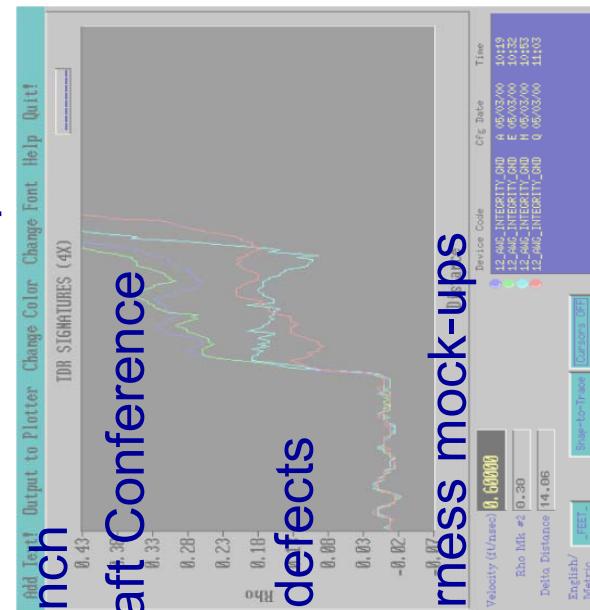
- Library of wiring component and defect EM physics models
- Algorithms for automatic wire defect detection
- Prototype “Hybrid Reflectometer”
- Coordinate with DOD, FAA, private wire advancements

► Present Status

- Modeled properties of coax with defects; Simulated TDR response
- Validated computer models with TDR on bench
- Delivered research paper at ‘02 Aging Aircraft Conference

► Next Steps

- Complete library of Orbiter wiring models & defects
- “Tune” TDR, FDR stimuli
- Validate models and stimuli response on harness mock-ups



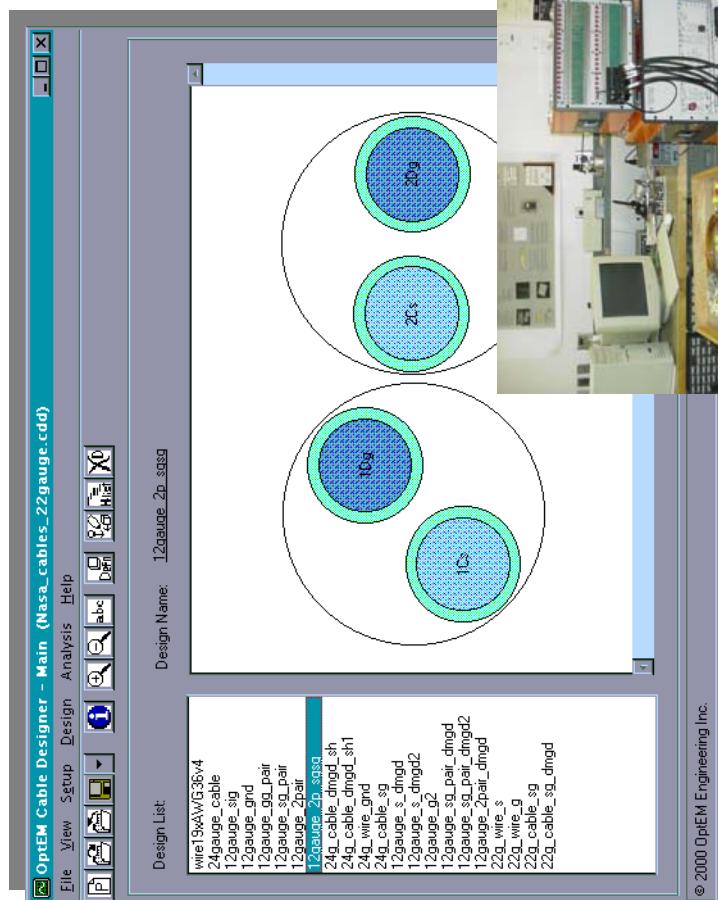
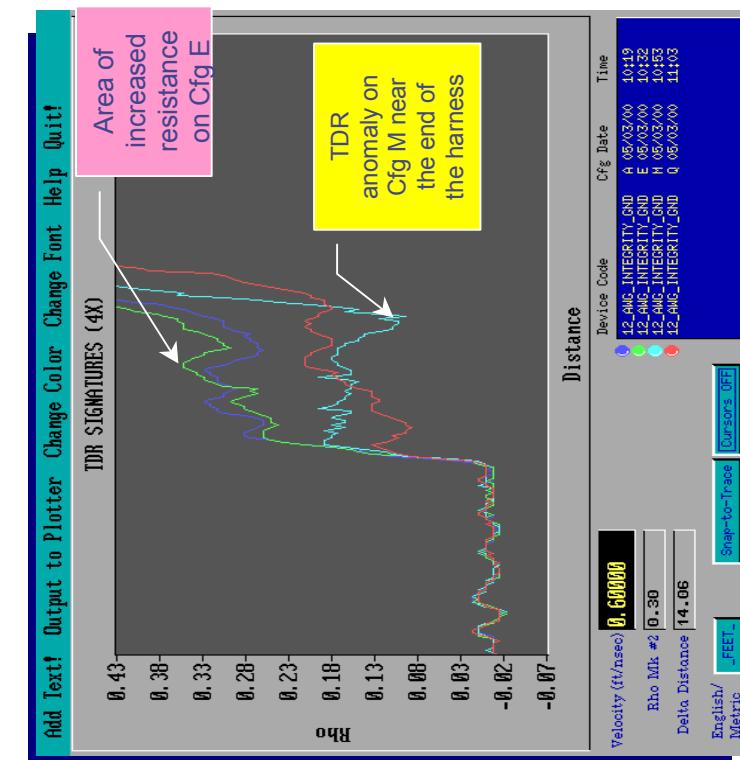


Hybrid Reflectometer Task



Hybrid Reflectometry

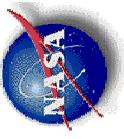
- High resolution, 3D computer models of wire electromagnetic fields
- Will model wire defects and features (connectors, splices...)
- Advance the understanding of wire response to reflectometry test stimuli



Hybrid Reflectometer



- ▶ Model wire EM field response to test stimuli
 - Including cables, connectors, splices, and “soft faults”
- ▶ “Tune” test stimuli
 - Combine advantages of Time- and Frequency-Domain (hybrid) reflectometry
 - Enhance sensitivity to impedance discontinuities of “soft faults”
 - Compensate for high frequency signal attenuation
- ▶ Develop automated “soft fault” detection algorithms
 - Inverse scattering; pulse compression; convolution
 - Signal processing techniques distinguish characteristic impedance of faults from cable features
- ▶ Automated signal interpretation eliminates expert operator
- ▶ Collaborations in progress
 - Goodrich Wire Diagnostic Systems
 - ♦ Algorithms for inverse scattering and pulse compression
 - ♦ Convolution algorithms to examine reflected impedances to detect subtle insulation problems in wire linkages
 - Dynacs (Pedro Medelius, KSC onsite contractor for orbiter electrical systems)
 - University of Utah (Dr. Cynthia Furse - exchange wire/defect models?)
- ▶ This year deliver library of wire and defect models
- ▶ Present paper on modeling for Aging Aircraft Conference FY03



Wire Risk Assessment Tool

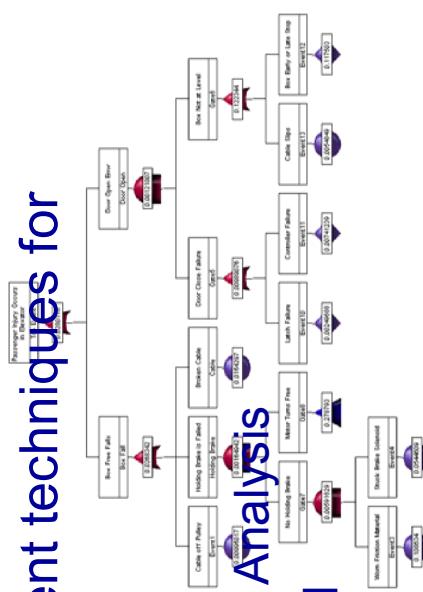


Wire Risk Assessment Tool

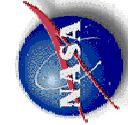


Wire Risk Assessment Tool

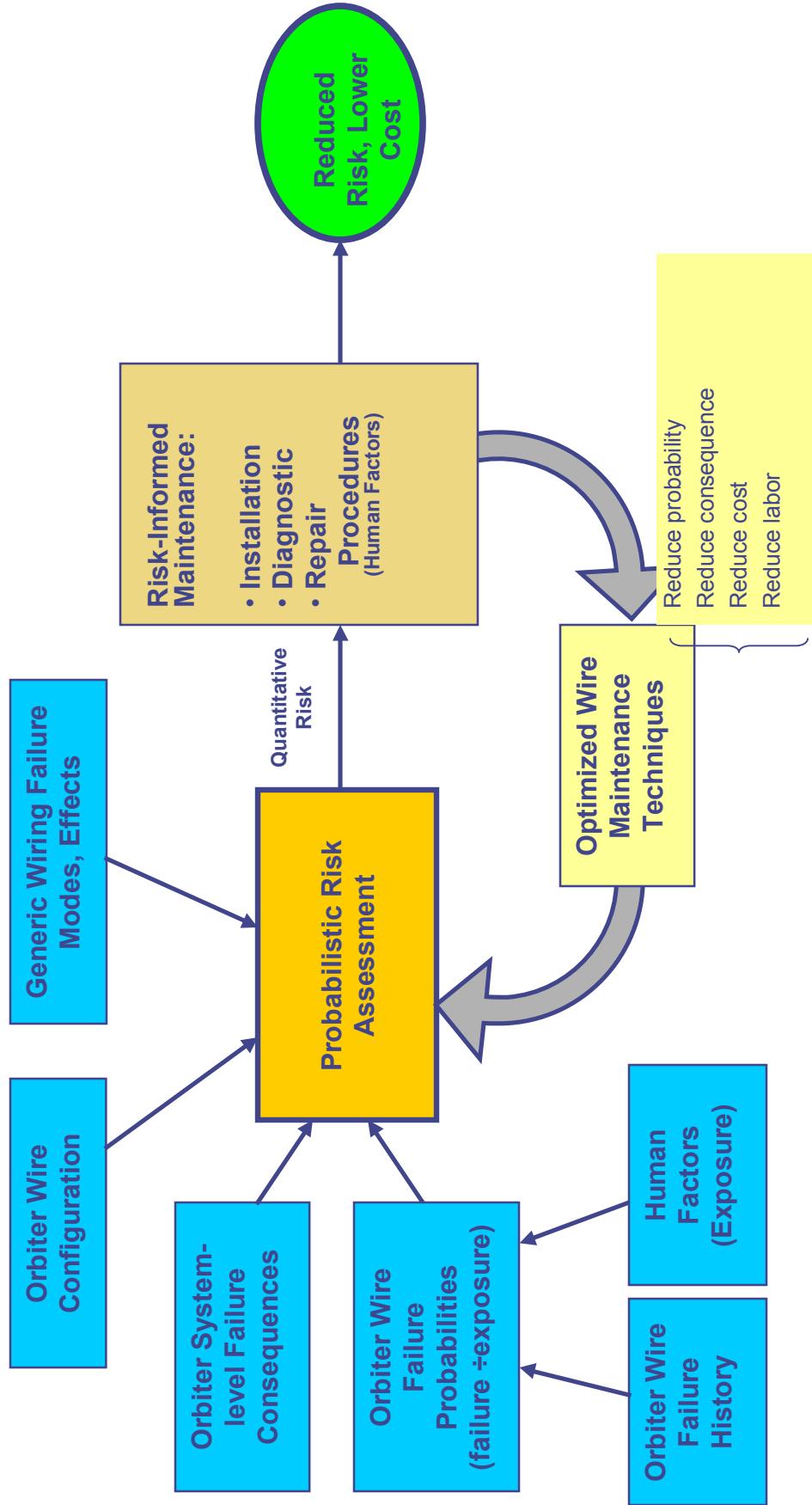
- Objective
 - Explore the use of quantitative risk assessment techniques for optimizing wire maintenance procedures
- Deliverables
 - FY04 Report: Wire Risk Assessment Cost-Benefit Analysis
 - Follow-on: Continuously Updated Wire Risk Model
- Status
 - Work agreement with USA and Boeing SFOC:
 - ◆ Obtained “Wire Data” - PRACA, O&M, SCAN, and expertise
 - ◆ Began human reliability analysis for wire processes in OPF
 - Created wire database from SCAN for future fault tree analysis
- Next Steps
 - Refine preliminary Risk Model; perform sensitivity analysis
 - Analyze PRACA, wire OMIs, OIC logs, etc.; populate model
 - Complete Human Factors Study in OPF



Wire Risk Assessment Task

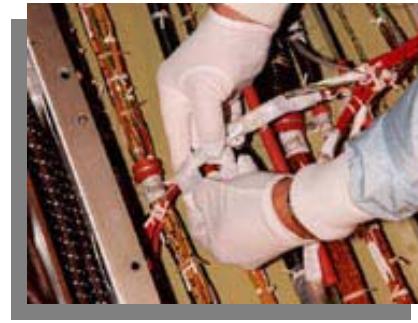


Wire Risk: the likelihood that wire damage will occur and will impact mission objectives, schedule, cost, or safety

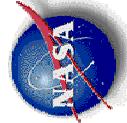


WiRe Risk Assessment

- Completed end-item requirements analysis
 - Initial focus will be damage probability, impacts to costs
- Completed WBS
- Proceeding with Human Factors observations, process analysis, activity logs, and initial HRA models
- Proceeding with initial risk models
 - Will use Markhov models of wire state transitions (from good/inspected, good/not inspected, damaged, failed)
- Proceeding with PRACA and other database analysis
 - Analyzing root cause, location distributions of damage
- Challenges
 - PRACA data not well resolved in location or time
 - Budget and schedule constrain risk assessment scope:
 - ◆ Initial focus on damage probability
 - ◆ Initial focus cost impacts (cost risk)
 - Detection, inspection, disposition, record keeping costs



Wire Risk Assessment

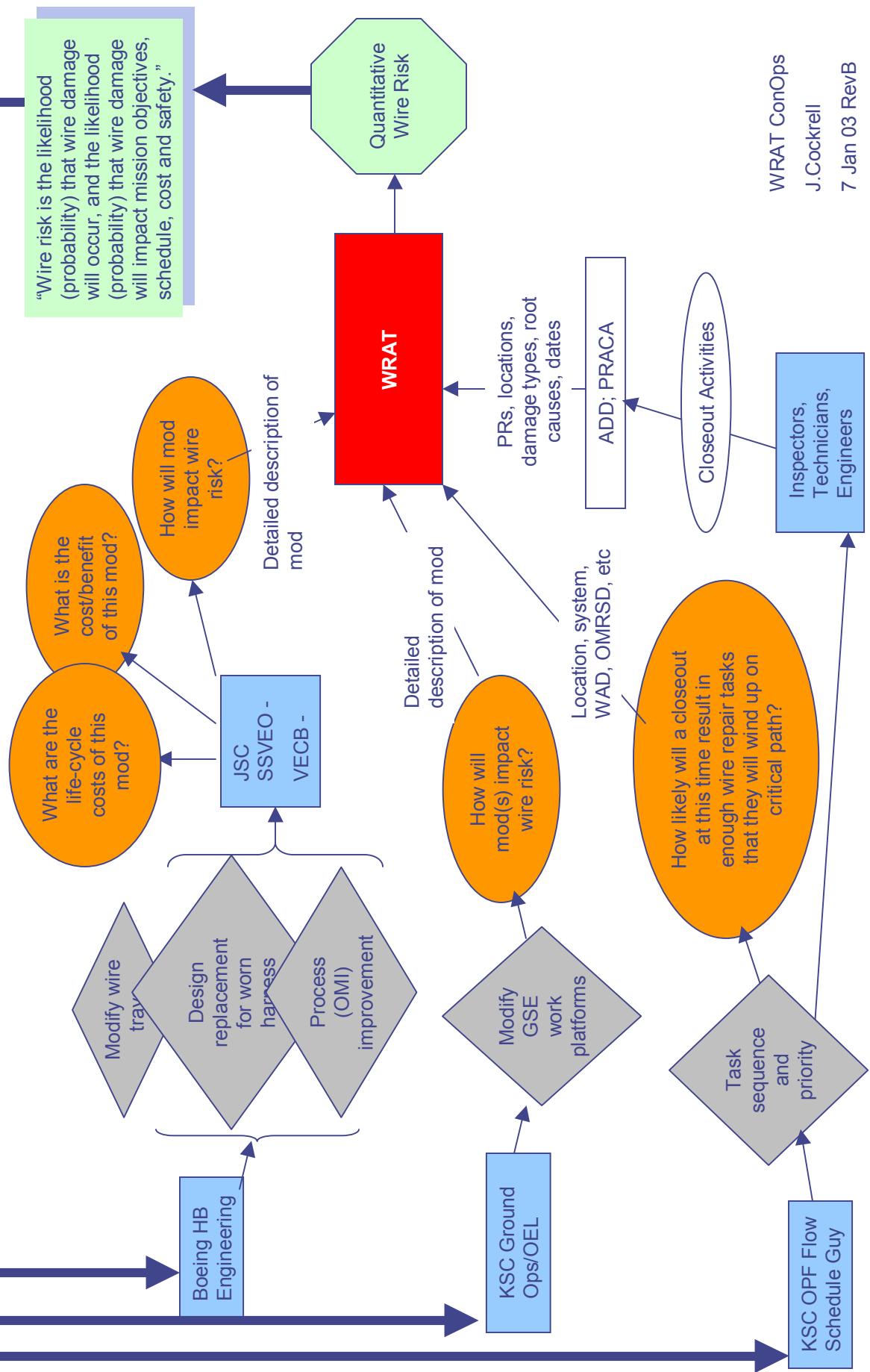


Req No. Measurable Requirement

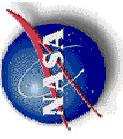
- 3 Specify and rank the top 5 root causes of wire damage, in order of risk magnitude (likelihood and impact) with an agreed upon accuracy and confidence factor.
- 7 Quantify risk (likelihood and impact) with an agreed upon accuracy and confidence factor, and locate risk as a function of wire harness location, with a spatial resolution of +/- TBD units on the outside surface of a harness, or resolution of +/- TBD units in an Orbiter Zone.
- 10 Provide an analytical assessment of risk (likelihood and impact) with an agreed upon accuracy and confidence factor to assist decisions about operations (as defined below), or design (as defined below) with quantitative risk information. Operations decisions include: process improvements to reduce risk; process improvements to reduce the time and labor costs or rework; prioritizing inspection locations [note - can these be quantified?] Design decisions include: trade studies for mechanical wire protection (wire tray covers, convoluted tubing, etc); improvements to work platforms to reduce wire risk; etc.
- 8 Specify and rank the top 5 influence factors that affect wire risk, in order of risk magnitude (likelihood and impact).
- 2 Will estimate the type and degree of wire damage likely to occur and the level of effort required to bring back into specification
- 13 Capable of estimating time-to-repair, based on probability of wire damage likely to occur in a given area (or volume) before closeout of a given mod or inspection or other activity.
- 32 Provide a means of making a wire-by-wire repair/replace decision based on risk (likelihood and impact) with an agreed upon accuracy and confidence factor.
- 11 Recommend 3 or more improvements to training, based on studies of most likely wire damage attributed to human factors and influence factors.
- 17 Identify the 5 most probable wire damage types and locations, to guide development of testing tools (specifically for use to detect those damage types, and adapted for use in those locations).
- 25 Advise when to replace wire (type, size, subset, material) based on quantitative factors including cost to replace vs. cost to diagnose and repair, based on probability curve of wire damage over time.
- 31 Provide quantitative risk (likelihood and impact) with an agreed upon accuracy and confidence factor, to assess trade between cost of inspection vs. risk of loss of vehicle.

WRAT Concept of Operation

Quantitative Wire Risk



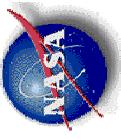
WRAT ConOps
J.Cockrell
7 Jan 03 RevB



Test Management Software



Test Management Software



Test Management Software



► Deliverables

- Report: Evaluation of laser scanning for 3-D wire harnesses
- Prototype 3-D wire “point of interest” locator system
- Report: Using COTS TM SW for PR, disposition automation

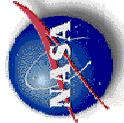
► Present Status

- Market survey for 3-D pointing device
- Case study laser scan for 3-D wire harnesses

► Next Steps

- Conceptualization, user requirements,
- Laser scan of Orbiter wiring for 3-D wire case study
- Vendor survey of “3-D pointing device”

Test Management Software Task



► Integrate COTS Test Management Tools into OPF, to:

- Track test coverage
- Auto-update ADD, including 3D PR location
- Issue PR and corrective action instructions, automatically (relieve engineers of repetitive paperwork)
- Prioritize integrity inspections and tests, based on
 - ◆ Risk priority
 - Prioritize harnesses of greatest criticality and most likely damaged
 - ◆ Availability
 - Shuttle Connector Analysis Network updated daily with “demeate” status
 - Perform electrical “tests of opportunity”
 - Perhaps harnesses handled each flow more likely acquire damage?



Transmitter/
Receiver (3 ea)

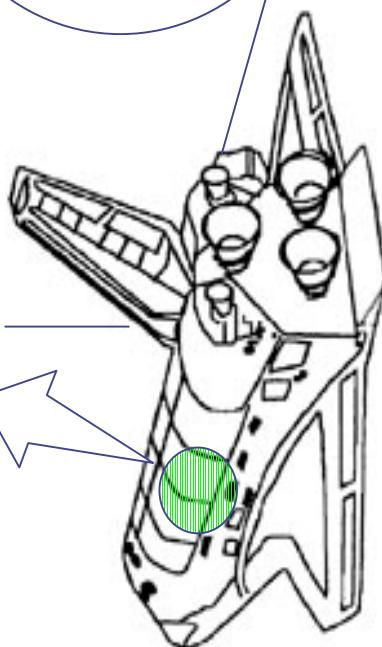


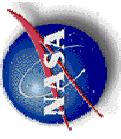
Display

X_o = 941.6
Y_o = -86.4
Z_o = 347.8

Plastic
Pick-up

Location Aid





WiRe Test Management Software



- Preparing specs, market survey for 3-D pointing device
 - Enables operators to record points of interest (e.g. PR location) in Shuttle coordinates, in confined areas
 - Many applications beyond wire
- Leveraging Digital Shuttle laser locating technology to explore “as-built” 3-D wire installation drawings
- Working with KSC Electrical ground ops to establish concepts and requirements for software to automatically generate disposition instructions from PRs



WIRe V&V



- Results of each WIRe element - Hybrid Reflectometer, Wire Risk Assessment, and Test Management SW - will be independently validated.
- WIRe validation activities scheduled 3Q FY05 - 4Q FY06
- Approach
 - Hybrid Reflectometer
 - ◆ Each wire and defect model of library is validated comparing modeled TDR response to response obtained on bench from actual TDR on Ames wire/defect test beds (and possibly on Sandia National Labs or AFRL test beds)
 - ◆ Stimulus tuning, and defect detection algorithms implemented in prototype Hybrid Reflectometer will be verified on Ames test beds and under AFRL Wire Integrity Characterization and Evaluation Program (AT&T contract) test beds. The AFRL Program will provide performance comparisons of Hybrid Reflectometer technique with cross section of integrity test methods (commercial and emerging technologies).



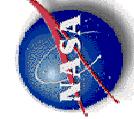
WiRe V&V



- ▶ Approach (cont'd)
 - Wire Risk Assessment
 - ◆ 1 (minimum) to 3 (maximum) risk mitigation strategies will be proposed in consultation with subject matter experts in KSC Electrical Ground Ops and JSC Vehicle Engineering. Quantitative risk delta predicted by Wire Risk Model will be validated against actual implemented mitigation(s). A report will be provided.
 - Test Management SW (including 3-D Wire)
 - ◆ Harness models (in Pro-E format) will be verified against "as built/as maintained" configurations
 - ◆ Report on 3-D Wire Harness modeling, cost/LOE comparison to manual methods, will be cross-validated against analogous Digital Shuttle studies.
 - ◆ Automated wire repair disposition/trend analysis will be validated against manual methods.



ECS Work Breakdown



3.0

Knowledge Engineering for Safety and Success
Project Manager: Patricia M. Jones (ARC)
Deputy Project Manager: David M. Bergner
(ARC)

3.2

Engineering Information Management; David Maluf (ARC)

3.2.1

Lifecycle Systems Integration; Paul Keller (ARC)

3.2.2 (terminated)

Inter-Organizational Process Analysis
Barbara Kanki (ARC)

3.2.3

Virtual Iron Birds; Paul Keller (ARC)

3.2.4

Digital Modeling; Michael Conroy (KSC)

3.2.5

Wire Integrity Research
Jim Cockrell (ARC)



Budget Information

- WIRE funding levels

	FY02	FY03	FY04	FY05	FY06
FUNDING (In \$K)	750	650	650	700	750
Civil Servant FTEs	1.8	2.0	1.8	1.8	1.8
Contractor FTEs	2.7	2.1	2.35	2.2	1.7
Staffing Total in FTEs	4.5	4.1	4.15	4.0	3.5

